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Noise
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1pNSa8. Implementing 24-hour in-ear dosimetry with recovery

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In order to further understand the combined effects of occupational and recreational noise exposure with regards to noise induced hearing loss (NIHL), an in-ear dosimeter prototype meant for continuous use was developed. The device acts as a hearing protection device (HPD) and can measure and log effective in-ear sound pressure level as well as unprotected levels. To enable its continuous use, this HPD is also equipped with a bypass feature for 'transparent' hearing, input for music or communication devices and interfaces with Android smartphones. The proposed device allows for the implementation of an algorithm accounting for the auditory fatigue recovery rate, providing a true representation of the current accumulated noise dose. This allows for 24h dosimetry and avoids having the user manually reset the dose back to 0% on the next day and thus assuming complete fatigue recovery has occurred. This paper details the proposed recovery algorithm, presents the field data to be collected and discusses the expected benefits as well as foreseen real-world challenges of using such a device.

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INTRODUCTION

Noise induced hearing loss (NIHL) has been considered a serious occupational health hazard for more than 50 years and is now increasingly becoming a concern for the general public. Despite the news headlines, most scientific studies state that more empirical data is necessary for proper assessment of NIHL prevalence among the general population (Mahboubi et al., 2012; Tak and Davis, 2009).

The popularity of personal media players (PMP) is hard to ignore, in recent years the consumer market has bought more headphones than loudspeakers (Levin 2011). The ability of these devices to cause permanent hearing damage has been well documented in literature, even leading to recently updated technical safety standards in the European Union, requiring devices to default to safe listening levels and warn the user if the level is thought to exceed 85dB (EU, 2013). Although listening habits are highly inter-individual and hard to accurately objectively assess, research suggests that many individuals are at risk (Levey et al., 2011). The growing concern is that the combination of PMP use with loud recreational activities or occupations can amount to hazardous exposure levels.

Conventional 'personal' dosimeters do not easily interface with PMP, communication and hearing protection devices (HPD) (Portnuff et al., 2012) nor are they meant for 24-hour use. Not only is it quite difficult to keep track of noise exposure accumulated over a 24-hour period; there are few guidelines to follow. Current legislation is designed for 8hr work-shifts and based on a 16hr recovery period in a 'relative quite' environment (<75 dBA). In 1974, The Environmental Protection Agency (EPA) stated that a 24-hour L_{eq} of 70 dB "…will protect public health and welfare with an adequate margin of safety" (Mazur and Voix, 2012).

Recent research revisiting noise exposure and associated physiological costs, through the assessment of temporary-threshold-shifts (TTS), emphasizes that the current damage risk criteria used in noise dosimetry does not adequately represent the associated risk. In order to accurately assess the potential damage, the spectral and temporal characteristics of the noise exposure must be taken into account, yet current metrics fail to do this (Kostek et al., 2012; Strasser et al., 2008).

Proposed Approach

A recently proposed 'Psychoacoustic Noise Dosimetry Model'(Kostek et al., 2012) is being adapted for individual use onboard the Auditory Research Platform (ARP), a hardware device developed by the authors. The system consists of two main components, shown in Figure 1, the earpiece instrumentation hardware and the accompanying digital signal processing (DSP) electronics, currently contained within a belt-pack. Each earpiece contains two microphones, an In-Ear- Microphone (IEM) and Outer-Ear-Microphone (OEM), as well as a balanced-armature speaker (Mazur and Voix, 2012).

The availability of accurate miniature microphones and popularity of smartphones makes the embedding of advanced 'personal noise dosimeters', such as the one presented here, quite practical. Ideally, allowing for the tracking of personal noise exposure levels as easily as current weather alerts.

The next section will discuss the real-world usability of such a device as experienced by the first author during initial use. Next, the 'Psychoacoustic Noise Dosimetry Model' is described and compared to real TTS measurements and finally a sequential function chart of the proposed recovery algorithm is presented.

USABILITY

Due to the nature of the ARP's intended 24-hour measurements, usability was a primary concern. In order to address earpiece comfort during prolonged use, the instrumentation hardware is integrated into a custom-fit silicone HPD; developed by Sonomax Technologies Inc. (Montreal, Canada). Very similar earpieces have been successfully used in brain plasticity research that required them to be worn continuously for 8 days (Schönwiesner et al., 2009). Although the earpieces can be removed at night, the ARP will continue monitoring room background noise levels (while being charged), assuring adequate time and effective silence for recovery.

Another primary concern was the ability to interface with communication devices and PMPs. Currently, the ARP is compatible with certain Android devices and computers using Bluetooth and USB, but also includes a 3.5mm jack for other devices. Ideally, the user should be able to continue naturally using their current devices, while monitoring their noise exposure.

In order to allow face-to-face communication a 'transparent hearing' mode was implemented using the OEM located just at the entrance to the user's ear canal. Although this is known to affect localization, care was taken to place the microphones as close to the ear canal entrance as possible. Provided some time for adaptation, subjective preliminary tests showed adequate lateral localization for common day-to-day activities.

The benefits of using such a device include, a deep longitudinal look into individual exposure levels and the tracking of effectiveness of suggested precautions. Since the system interfaces with the user's smartphone, immediate user feedback is possible. Initial tests by the first author conclude practical usability adequate enough for further field-testing. Most immediate improvements include a friendlier Android user interface.

FIGURE 1. Photo of the Auditory Research Platform (ARP) developed by the authors. Near the top are the pair of custom silicone earpieces, each containing two microphones and a dual balanced armature driver. They are plugged into the black box on the left, which is the belt-pack containing the Digital Signal Processor (DSP) and associated electronics. On the right is the Nexus 7 Android tablet running a beta version of the software.

PROPOSED DOSE AND RECOVERY ALGORITHMS

Background

NIHL is the result of overexposure to noise (or music) as a function of: sound pressure level and frequency distribution as well as duration and temporal spacing. Thus, in order to assess potential damage, the spectral and temporal characteristics of the noise must be properly accounted for while tracking recovery time post-exposure. The current standard metric, an A-weighted equivalent sound level (L_{eq}), which often for convenience is translated to a dose (%) value, fails to do so. Recent studies revisiting the physiological damage, by measuring TTS, post-exposure to: noise (white, pink brown), varying impulses, music (classical, electronic, heavy metal) show varying levels of physiological stress, despite having the same L_{eq} dB(A) values (Irle et al., 1998; Ordónez and Hammershøi, 2004; Strasser et al., 2008). In the 60's when A-weighting became common practice, along with the 3dB *exchange rate*, it was known that these where merely necessary approximations due to the complexity of performing the measurements (Johnson et al., 2010). This is no longer an issue with modern transducers and DSPs.

Noise Dosimetry Model

A "Psychoacoustic noise dosimetry model" intended for real-time use has been recently developed and validated in a study at several dance clubs. The model takes into account the excitation of the basilar membrane occurring in the inner ear, has provisions for impulse noise using time constants for the acoustic reflex, and includes the metabolic and structural components of Asymptotic Threshold Shift (ATS) to predict TTS as well as recovery time given a particular noise exposure (Kostek et al., 2012; Kotus et al., 2008). The growth and decay variable was selected using linear regression and mean square on data collected from small groups (~30 subjects). The results of the model versus measured data, including standard deviation, can be seen in Figure 2. While the model fits the average values very well, the inter-individual variability remains quite large. A similar study, using the same white noise stimulus (94 dB L_{eq} for 1hr), also had large inter-subject variation, with TTS_2 (TTS measured 2 min post-noise exposure) values (at 4 KHz) from 15-28 dB, recovery from 40 min – 165 min, and showed even larger variations with the introduction of impulse noise (TTS_2 = 16-36 dB, recovery 55-240 min) (Irle et al., 1998).

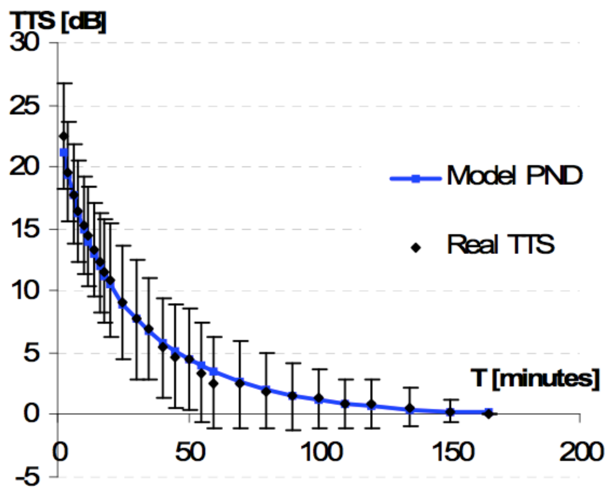

FIGURE 2. Data verifying the "Psychoacoustic Noise Dosimetry Model", after exposure to 94 dB L_{eq} of white noise for 1hr. The model follows the average values of real measured TTS very well, but fairly large individual standard deviation still exists. Figure is used with explicit permission from the authors (Kostek et al., 2012).

The proposed contribution adds a feedback mechanism to the model, described in Figure 3, to fine-tune the algorithm on an individual basis. Data collection takes place using the ARP hardware and Android interface. The assumption is that intra-individual differences will be lower and the algorithm will more accurately predict and thus actually warn users before the onset of TTS. The regression values from the above studies will be used as initial values and once the algorithm predicts the user to have TTS, it will prompt for a field TTS_2 measurement. The TTS_2 value at 4 KHz will be assessed and compared to the estimated value; with a follow-up TTS test after the estimated recovery time has passed (Figure 3, block 4 and 5). These variables are defined as TTS_2 and t(0dB) (Irle and Strasser, 2005). If the collected data differs from the estimated values the variables will be updated. The device will also concurrently run conventional L_{eq} and dose calculations for comparison.

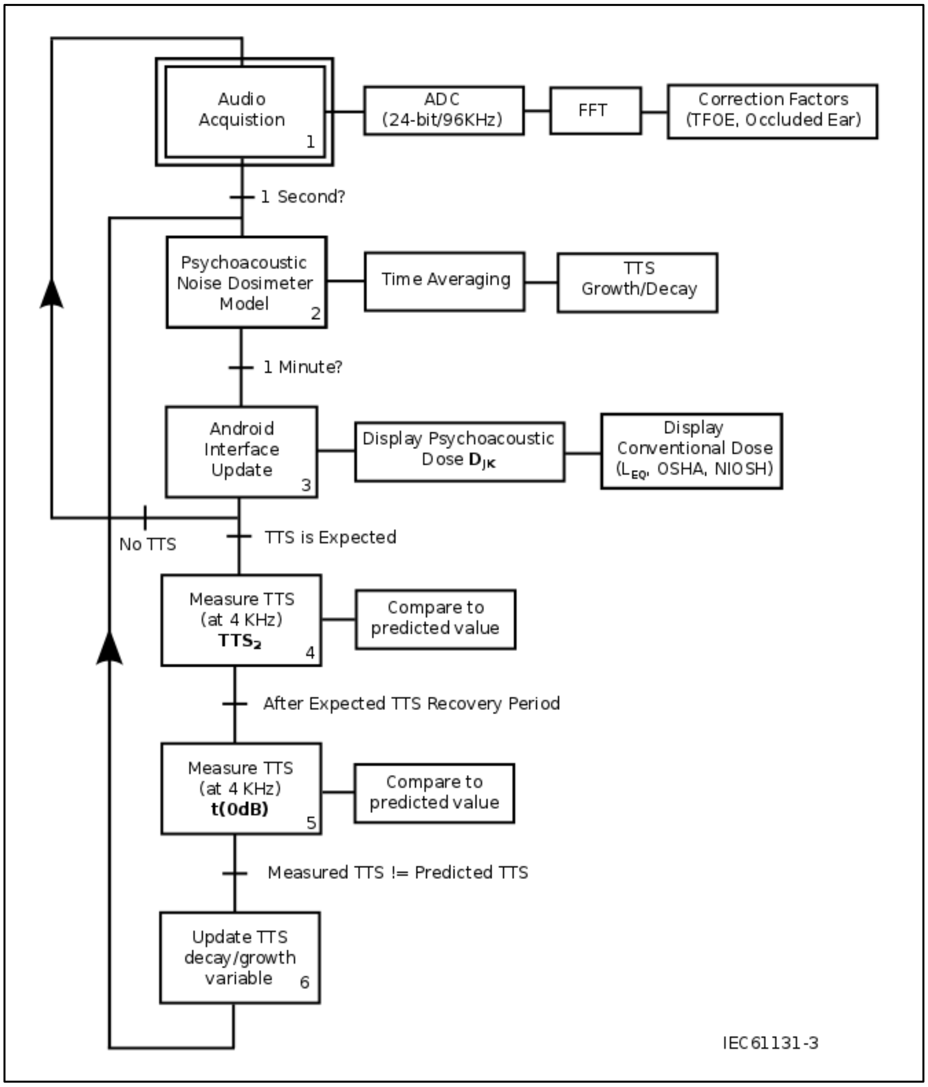

FIGURE 3. Sequential function chart of the proposed dose and recovery algorithms. Block 1 is the sampling of the noise signal using the earpiece microphones, Block 2 is the "Psychoacoustic Noise Dosimeter Model" (Kostek et al., 2012), Block 3 is the Android software interface, Block 4 and 5 represent the in-situ TTS measurement using the ARP hardware and Android interface to update the variables in the dosimeter model (2) on an individual basis.

CONCLUSIONS

Conventional 'personal' noise dosimeters do not easily interface with PMPs (Portnuff et al., 2012), communication and HPD devices nor are they meant for 24-hour use. Current legislation and damage risk metrics do not adequately account for important parameters such as: spectral distribution, impulse content and recovery time.

The ARP prototype has been designed with usability as a priority and features: in-ear and outer-ear microphones for dosimetry, is implemented inside a custom-fit HPD with a bypass for 'transparent hearing' and interfaces with communication devices and PMP. The DSP processing of the device allows for the real-world verification of new algorithms, such as the proposed noise dosimetry, leveraging the ARP Android interface to fine-tune variables on an individual level using in-situ measurements.

Such a device has the potential to warn users on an individual level before the onset of TTS and the ability to gather longitudinal individual exposure data creating priceless noise exposure databases.

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